

Searching for Superhorizon Fluctuations in Heavy-Ion Collisions

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Abstract. In this talk I discuss novel explanations for the azimuthal correlations observed in heavy-ion collisions. I review some ideas about correlations and the evolution of heavy-ion collisions. Some aspects of the correlations observed in heavy-ion collisions may be indicative of the suppression of superhorizon fluctuations.

Keywords: super-horizon, fluctuations, correlations, elliptic flow

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1. Introduction

It has been argued that the data from RHIC experiments indicate that the matter created in heavy-ion collisions behaves as a nearly perfect liquid with viscosity near a lower bound predicted by string theory and by quantum mechanics. These conclusions are based largely on comparisons of hydrodynamic models to the shape of single particle spectra and v_2 for particles of different masses [1]. These conclusions depend crucially on the initial conditions assumed for the models, particularly the initial eccentricity [2]. Here, I show that the upper limit on v_2 fluctuations coincides with the fluctuations expected from Monte Carlo Glauber models of the initial eccentricity fluctuations.

The upper limit on v_2 fluctuations is derived without subtracting contributions from two-particle correlations unrelated to the reaction-plane. As such, either

- 1) Those correlations invalidate the models for the initial eccentricity,
- 2) the observed two-particle correlations are a manifestation of the correlations and fluctuations in the initial source,
- 3) or both 1) and 2) are true.

The structure of the correlations expected from the initial conditions will depend on the details of the expansion of the fireball: e.g. the formation time, the lifetime,

the characteristic size of the fireball, and the characteristic size of the correlations. In Ref. [3], Mishra et. al. argue that the longest wavelength fluctuations from the initial conditions of heavy-ion collisions may remain super-horizon throughout the evolution of the fireball. In this case, the long wavelength modes should be suppressed. I show that the suppression of these modes can explain a negative contribution to p_T correlations which was previously attributed to a recoil caused by a fast parton impinging on the medium. I argue that the strong correlations seen in heavy-ion collisions may not actually reflect correlations from fragmenting quarks or gluons (mini-jets) but rather may reflect correlations from lumpy initial conditions or from cluster formation at a phase boundary.

2. v_2 Fluctuations and Initial Conditions

Elliptic flow (v_2) measurements are sensitive to the shape of the initial overlap zone so v_2 fluctuations can reveal information about fluctuations and correlations in the initial geometry. Distinguishing between v_2 fluctuations $\sigma_{v_2}^2$ and non-reaction-plane correlations δ_2 (non-flow) requires knowledge of the reaction-plane or information about the $\Delta\phi$ -, $\Delta\eta$ -, charge-sign- or multiplicity-dependence of non-flow. Lacking this information, only the sum of non-flow and v_2 fluctuations can be determined $\delta + 2\sigma_{v_2}^2$. Then the upper limit on $\sigma_{v_2}/\langle v_2 \rangle$ can be calculated and compared to models of eccentricity fluctuations [4, 5].

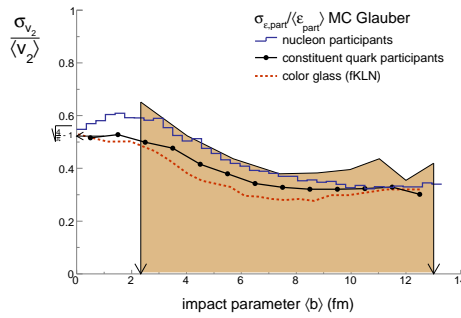


Fig. 1. Upper limit on $\sigma_{v_2}/\langle v_2 \rangle$ compared to models of eccentricity.

Fig. 1 shows the upper limit on $\sigma_{v_2}/\langle v_2 \rangle$ compared to several Monte Carlo models of ε_{part} fluctuations. All models lie within the allowed range while the CGC model [6] and the model based on constituent quarks inside the participating nuclei both have smaller relative widths. The nucleon participant model leaves little room for other sources of fluctuations and correlations beyond the initial geometric ones. The large near-side peak observed in two-particle correlations [7] contradict the idea that all or most of $\delta + 2\sigma_{v_2}^2$ is dominated by σ_{v_2} suggesting that the CGC or constituent-quark model may be preferred. Recently it was proposed that correlations and fluctuations in the initial conditions may also contribute to the near-side

ridge [8]. Either the density fluctuations in the initial state are manifested in both the near-side peak and in σ_{v2} , or the initial overlap density is smoother than would be expected from the MC Glauber model. The translation of fluctuations from the initial conditions into observed correlations has analogies with the expansion of the universe and the temperature fluctuations in the CMB.

3. Heavy Ion Expansion: It's About Time

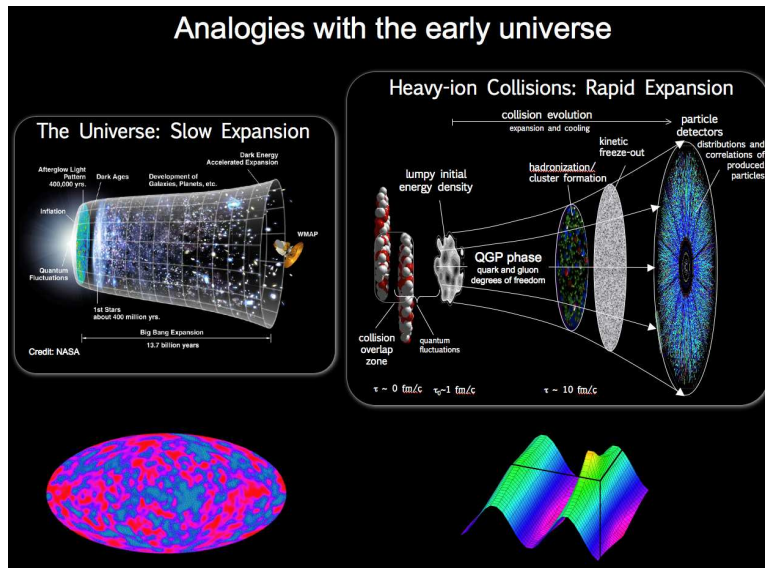


Fig. 2. This figure presents an analogy between the expansion of the universe and the expansion of the fireball created in heavy-ion collisions. The graphic on the bottom right shows p_T correlations measured by STAR which are analogous to the Temperature fluctuations shown on the bottom left measured by WMAP [9].

Measurements of the scale dependence of temperature fluctuations support the cosmic inflation scenario of cosmology. In this scenario, the temperature fluctuations in the cosmic microwave background radiation result from quantum fluctuations that are magnified during an inflationary epoch by a factor of $\approx 10^{30}$. The fireball created in heavy-ion collisions may last for as short as 10 fm. In this case, long-wavelength correlations in the transverse direction can remain super-horizon throughout the fireballs evolution and would therefore be suppressed in the observed power spectrum. Causality in the longitudinal plane has been discussed previously in [8] and references therein.

3.1. Yea, Though I Walk Through the Valley

Mishra et. al. propose measurements of the mean square values of flow coefficients $\sqrt{v_n^2} = v_n^{rms}$ as a way to test for the suppression of the long wavelength super-horizon fluctuations. v_n^{rms} values are related to two particle correlations which have already been measured by STAR. The measurements most closely related to the CMB measurements are the p_T correlations shown in Fig. 3. The figure shows p_T correlations after the v_2 like $\cos(2\Delta\phi)$ term has been subtracted (left) and then after the prominent near-side peak has been subtracted (right). The subtraction reveals a valley that was first interpreted as the medium recoiling from an impinging jet. This interpretation was motivated by the assumption that the near-side peak is dominated by the fragmentation of hard and semi-hard scattered partons (mini-jets). We show here that causality can lead to the observed valley through the suppression of long wavelength, super-horizon modes.

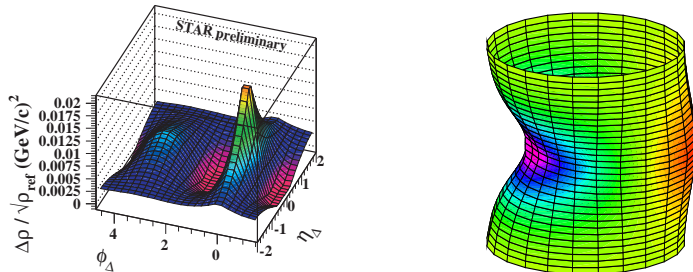


Fig. 3. Left panel: p_T autocorrelations derived from the $\langle p_T \rangle$ fluctuation scale dependence in $Au + Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV [10]. Sinusoidal modulations associated with v_2 have been subtracted. Right panel: p_T autocorrelations plotted in cylindrical coordinates. The positive *near-side* peak is subtracted revealing a valley [11].

In order to carry through the analogy with the analysis of CMB temperature fluctuations, we perform a similar power-spectrum analysis by calculating the coefficients in a spherical harmonic decomposition of the p_T correlation data. For simplicity we only consider the transverse direction at $\Delta\eta = 0.0$. In ref. [10], the p_T correlations are fit by a $\cos(\Delta\phi)$, a $\cos(2\Delta\phi)$, and three two-dimensional Gaussians. In Fig. 4 we show the power-spectrum derived from the Gaussian terms. The spectrum is shown with and without the negative Gaussian term (i.e. the valley). Note that the existence of the valley is related to the suppression of the longest wavelength modes (lowest harmonics). We conclude that the valley is evidence for suppression of long wavelength fluctuations due to the limits of causality and the brief duration of heavy-ion collisions.

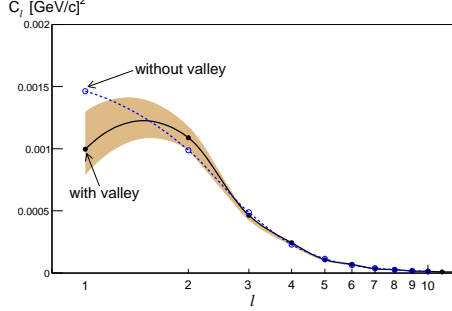


Fig. 4. The power spectrum from p_T fluctuations in heavy-ion collisions. C_l are calculated at midrapidity with $\theta = 0$.

4. Conclusions: Life is Short

The upper limit on the ratio of $\sigma_{v_2}/\langle v_2 \rangle$ coincides with the eccentricity fluctuations calculated from Monte Carlo Glauber models of the initial conditions. Removing non-flow correlations from σ_{v_2} will reduce the upper limit on the allowed values of $\sigma_{v_2}/\langle v_2 \rangle$. Significant two-particle correlations have been observed. We conclude therefore that either those correlations are a manifestation of correlations from the initial conditions, or the Monte Carlo Glauber model overestimates the fluctuations in the initial conditions.

The transfer of spatial correlations and fluctuations from the initial conditions to correlations in momentum space requires interactions between constituents. If these interactions do not persist for long enough, then long wavelength correlations will remain super-horizon. Given that the diameter of a Au nuclei is approximately 15 fm, if the interactions between constituents produced in a Au+Au collision only persists for 10 fm, then regions of the overlap zone will remain outside the event horizon. This is illustrated in Fig. 4.

Causality has been discussed with regards to the longitudinal axis but it can also play a role in the transverse plane as well. Examining p_T correlations, we find evidence for suppression of long wavelength fluctuations due to the limits of causality and the brief duration of heavy-ion collisions. The suppression of long wave-length, super-horizon fluctuations can naturally lead to the anti-correlation observed in p_T correlations which was previously ascribed to recoil from an impinging hard parton.

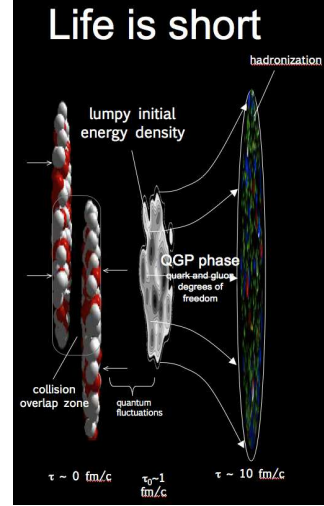


Fig. 5. A proper perspective.

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